Breaking wave impacts against a schematized Offshore Wind Turbine support structure

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HIGHLIGHTS

Breaking wave impacts against Offshore Wind Turbine support structures can cause accelerations in the nacelle that may lead to damage of bearings and other parts of the drive train. A systematic study, using numerical simulations and experiments, was conducted of how the mechanical properties of the structure influence the breaking wave load and response of the top end of the structure. The novel aspect of the study was the non-uniformity of the structure due to added mass and a mass added at the top.

1 INTRODUCTION

Monopile support structures for Offshore Wind Turbines (OWT) comprise the majority of what has been installed. These OWTs feature the monopile, a transition piece, the tower and the nacelle at the top that houses the drive train between blades and generator. Breaking wave interaction with the structure can lead to vibrations causing wear of bearings and other parts of the drive train in the nacelle. As maintenance cost in one study [1] were assessed to make up for more than 20% of the levelized cost of energy of an bottom-founded OWT, it seems advantageous to try to model the vibrations that lead to damage.

An OWT has strongly non-uniform mechanical properties along its main axis. Disregarding the geotechnical aspects of the monopile in soil, the OWT still features added mass along the part of its height that it is in water and a nacelle with a high mass. Breaking wave interaction with OWT support structures has been studied before. Some studies also considered the flexibility of the OWT through experiments [2], with proper scaling of the flexibility, or simulations [3] in order to be able to assess the accelerations in the nacelle. Few, however, seem to have systematically studied how the breaking wave load and the response of the top end of the structure depend on varying the aforementioned non-uniformities of the OWT.

This study has considered breaking wave interaction with a strongly schematized representation of an OWT by means of experiments and numerical simulations. The OWT was represented by a plate acting as a cantilever beam and exposed to focused breaking wave impacts, while measuring forces, deflections and accelerations. The objective was to establish how varying the relative magnitudes of the added mass and the top mass would change the breaking wave load and the motion response of the top end.

2 MATHEMATICAL MODEL

The interaction between breaking waves and the structure is solved with a two-phase approach representing water and air. A one-fluid approximation is applied yielding a single velocity and a single pressure field. The governing equations for conservation of mass and conservation of momentum of the fluid are discretized in space and time so that a system of equations for solving the pressure p at the new time level is obtained from the velocity field at the old time level. The fluid velocities $\mathbf{u}$ at the new time level are solved from the pressure gradients. The solution algorithm with verification and validation cases, can be found in Van der Eijk and Wellens [4]. The structure's motion, written as a state space system, is solved implicitly with the fluid motion.

3 EXPERIMENTS

The experiments were conducted in towing tank 2 of the Ship Hydromechanics Laboratory of Delft University of Technology. The towing tank has a wave board on one end of the tank and a wave spending beach at the other. A towing carriage can be driven over the tank guided by rails, but was kept at a single position halfway the tank's length. The model of the OWT was supported by the towing carriage by means of a frame that was designed to measure the horizontal breaking wave force on the structure. The vertical position of the frame could be adjusted to different submergence depths so that the added mass could be varied. The plate was attached to the frame, with one of its axes in the vertical direction and the other spanning almost the entire width direction of the tank. Different plate thicknesses were considered and different masses could be attached to the top end of the plates in order to represent the mass of the nacelle of the OWT. A schematic representation of the OWT model in the towing tank is shown in Fig. 1.

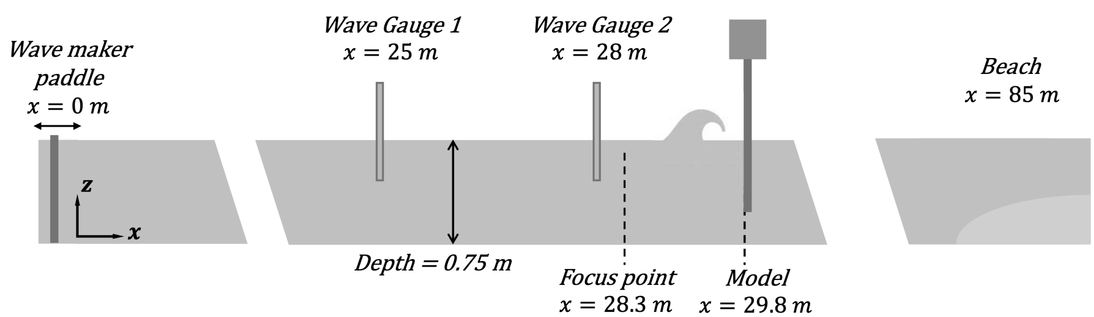

Figure 1: Overview of the setup of the experiment with breaking waves and a model of Offshore Wind Turbine support structure.

The water depth in the tank was kept the same at 0.75 m. A breaking wave was generated by making a wave train focus to a critical steepness near the position of the structure, after which the wave overturned before impacting the vertical plate. The wave board signal consisted of a number of superimposed wave packets of different frequency, slightly shifted in time from each other, with five individual waves each and a smooth envelope to ramp the signal of the packet up and down. At the focus point, the middle one of the five waves in each wave packet would focus with the other wave packet. The amplitudes of the wave packets were chosen to have a steepness of 1 over 40. Combining the small steepness with the wave packet approach made the focus point very predictable; the approach is also described in [5]. Breaking waves with different distances between the base of the plate and the focus position were considered to study the different types of impact. Upon impact, the wave would run up along the plate while it deflected under the load, causing an acceleration of the top mass.

The parameters that were systematically varied during the experiment in different tests were the plate thickness (so both mass and stiffness), the size of the top mass, the submerged depth of the plate and the focus position of the wave train. Each test was repeated 3 times to study the variability. During a test, the following quantities were measured. The surface elevation was measured with resistive wave gauges at two position near the focus position of the wave train. The horizontal load on the structure was measured by means of a force gauge in the force frame. Deflections of the plate were measured by means of laser position gauges. An accelererometer tracked the motion of the top mass. The deflections of the plate were measured using a high speed camera through a window in the side wall of the towing tank.

4 SIMULATIONS

Numerical simulations were performed to help design the setup of the experiment and to help interpret the outcomes of the experiment. A computational domain was generated with a cartesian grid and a grid size in all directions of 0.01 m. The domain had closed boundaries everywhere, except at the end where waves enter the domain. Because the structure also reflects waves, a generating absorbing boundary condition [6] was used to allow reflected waves to leave the domain while incoming waves enter the domain. The location for the boundary was chosen to coincide with the position of the wave gauge in the experiment that was closest to the wave board. The measured signal at that position was transformed to its frequency components so that linear potential wave theory could be used to impose the time-varying velocity profile. The structure was places at the same distance away from the wave gauge as in the experiment. The time step in the simulations varied according to the CFL number appropriate to the time discretization. In the simulations, the waves would focus, break and cause an impact on the plate. Simulations would finish when the impact was over. The output of the simulations consisted of the same signals that were taken from the experiments.

Preliminary results of the comparison between the experiment and the simulations are shown in Fig. 2. The figure shows the force from the experiment, 2D simulations and 3D simulations for different values of the submergence depth d/L of the base of the plate, in which L is the length of the plate. The maximum force increases with submergence depth, because the area in contact with water increases. The forces in simulation and experiment are highly similar. The results show that for larger submergences, the effects of 3D diffraction around the force frame could not be ignored.

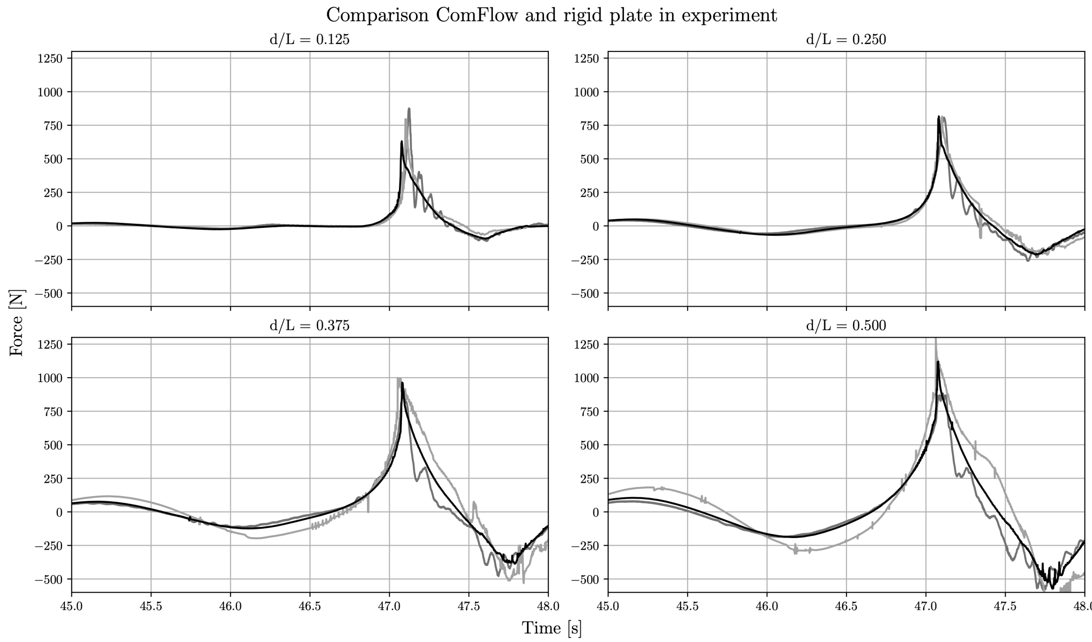

Figure 2: Force on the model for different values of the submergence of the base in the experiment (dark gray), 2D simulations (light gray) and 3D simulations (black).

5 CONCLUSION

A study of breaking wave impacts against a model of an Offshore Wind Turbine support structure was conducted using an experiment and numerical simulations. The mechanical properties of the model were systematically varied to investigate the effect of the variations on the magnitude of the load and response of the structure. Preliminary results show the impact forces for different submergence depths of the base of the model to be highly similar between experiment and simulations. More results will be shown at the workshop.

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